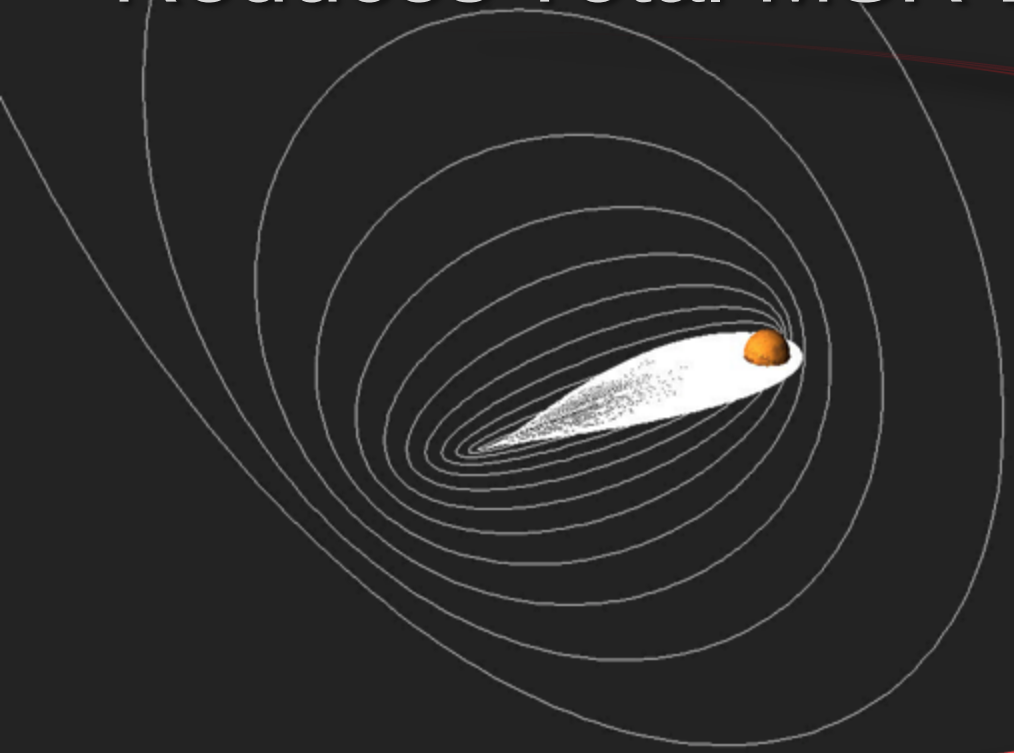
Using A Solar Sail to Significantly Reduces Total MSR Launch Mass



MSR From Decadal Survey Report

National Aeronautics and Space Administration

- Orbiter arrives ahead of lander with Mars Ascent Vehicle
  - Orbiter provides observation of MAV lander EDL and comm. link post-landing
- Orbiter is active participant in the orbital rendezvous and capture of the sample canister launched from Martian surface
- Orbiter captures into highly elliptical Mars orbit and aerobrakes to 500 km circular
  - Mars Orbit Insertion ΔV = 1090 m/s
  - Earth Return ΔV = 2000 m/s
- Orbiter uses 4 Hi-PAT 200 lbf bi-propellant thrusters
  - Isp = 325 seconds / Chamber Pressure = 425 – 100 psia

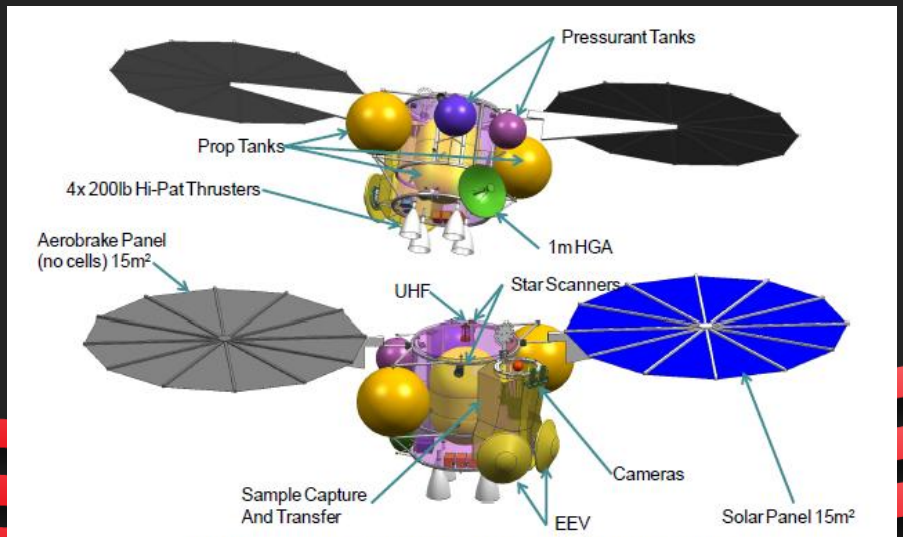
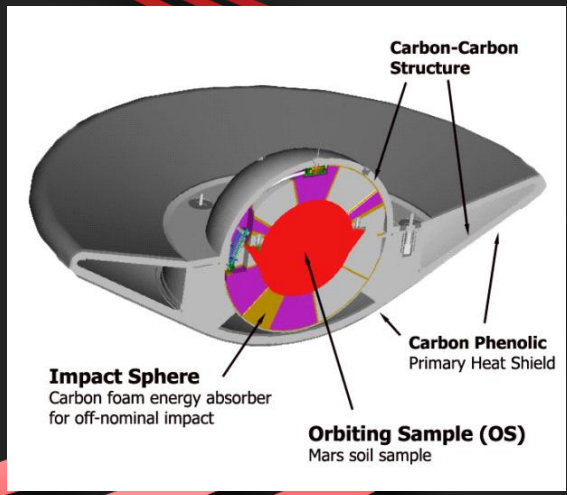


Figure 3-1 Preliminary Orbiter Configuration



Estimated MSR Savings with Solar Sail

National Aeronautics and Space Administration

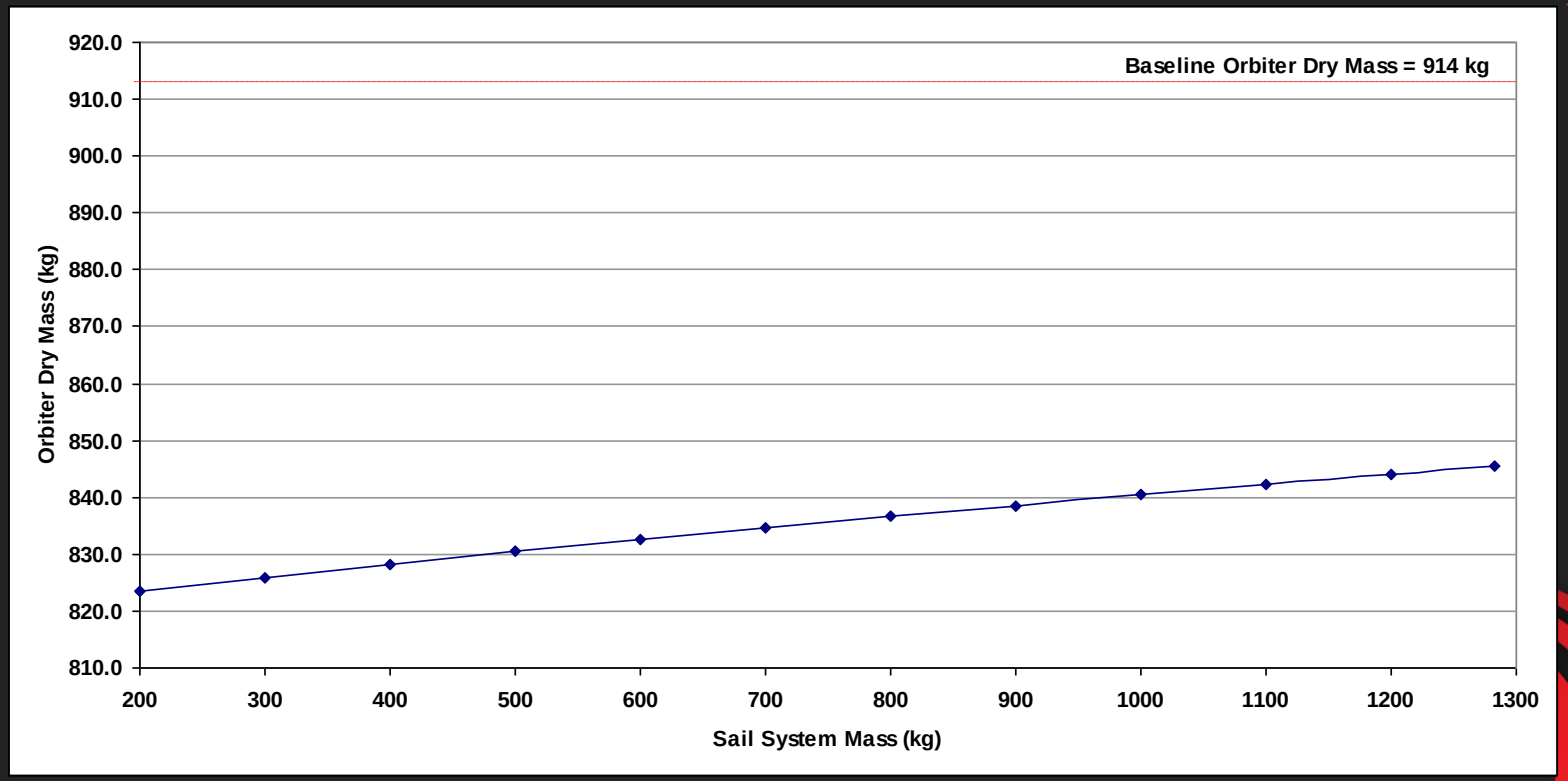
	Baseline Case	Sail Return	Sail Capture & Return
Launch Mass	**3270.9**	**2082.0**	**1384.1**
Launch Vehicle Adapter	**30**	**30**	**30**
Orbiter Dry	**913.7**	**831.2**	**761.8**
Structures & mechanisms	339.2	339.2	339.2
Thermal control	35.6	35.6	35.6
Propulsion (dry mass)	171.9	89.4	20
Attitude control	35.1	35.1	35.1
Command & data handling	26.6	26.6	26.6
Telecommunications	32.9	32.9	32.9
Power	128.4	128.4	128.4
Cabling	42.9	42.9	42.9
System contingency	101.1	101.1	101.1
Orbiter Propellant	**2279.9**	**673.5**	**45.0**
Burned Propellant	2011.2	594.1	40.0
Reserve Propellant	268.7	79.4	5.0
Earth Entry Vehicle	**47.3**	**47.3**	**47.3**
Structures & mechanisms	23.6	23.6	23.6
Thermal control	0.6	0.6	0.6
Thermal Protection (TPS)	22.5	22.5	22.5
Range Beacons	0.2	0.2	0.2
Sensors & cables	0.4	0.4	0.4
Sail System (est)	**0**	**500.0**	**500.0**

Estimated Savings with Sail, continued

- **For Sail Return case, orbiter dry mass is dependent on sail system size**
  - Orbiter still performs the 1090 m/s MOI burn with the Hi-PAT thruster system
  - System was resized to account for smaller propellant load
- **For Sail Capture & Return case, orbiter still requires small RCS thruster system for rendezvous and capture of sample**
  - Propulsion system size provided is an educated guess with no supporting analysis

– Sail characteristic acceleration of >0.48 mm s^{-2} required for single revolution return trajectory; **100m square sail** requires **assembly loading of order 14 g/m^2** assuming **50 kg 'non-sail' mass**
  - Diminishing returns for higher performance sail
  - Mars escape in ~1¼ years
  - Mars – Earth transfer in ~1 ½ years
  - Earth 'impact' <3 years after sample launch
  - Earth 'impact' ~2 years (?) later than chemical mission
    - Ops cost trade…

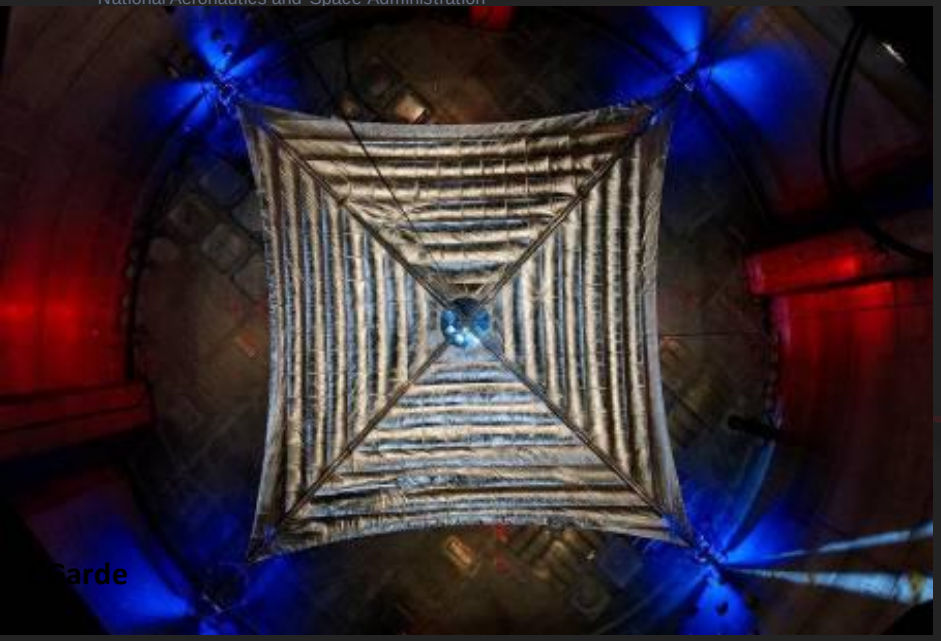
Sail Return Case: Sail Mass Dependency

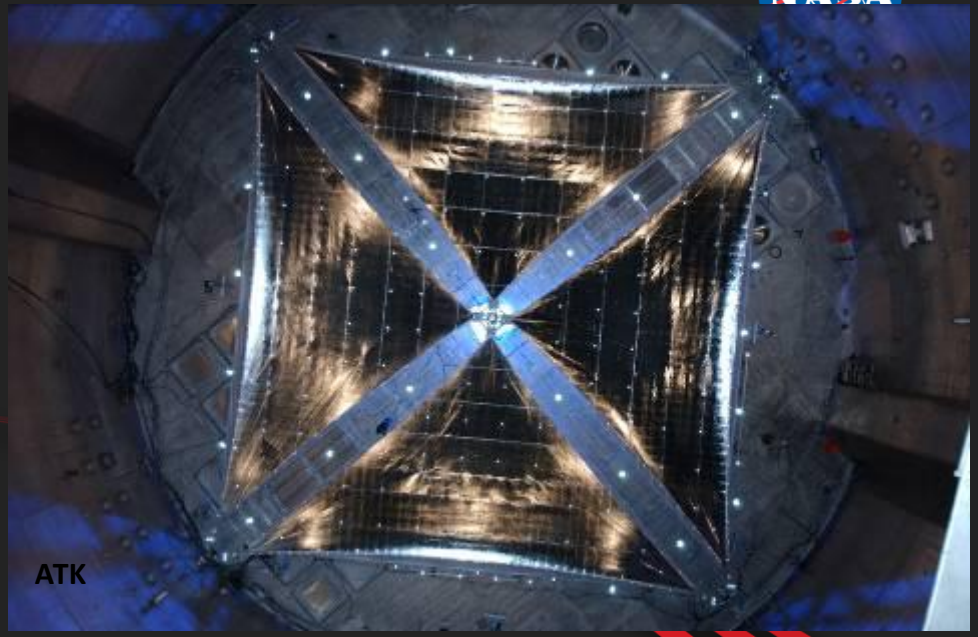


- **Previous slide provided a point design for the 500 kg sail case**
  - Parametric analysis performed to provide spectrum of sail sizes ranging from 200 kg to the 1283 kg sail that brings launch mass back to baseline 3271 kg

Solar Sail Propulsion Technology

National Aeronautics and Space Administration





- Two parallel awards to design, fabricate, and test competing sail concepts for system level ground demonstration over from 2003 - 2005
  - Phase A Concept Study in 2003
  - 10 m system ground demonstrators were developed and tested in 2004.
  - *20 m system ground demonstrators designed, fabricated, and tested under thermal vacuum and flight conditions in 2005.*
- Multiple awards to develop and test high-fidelity computational models, tools, and diagnostics.
- Multiple awards for materials evaluation, optical properties, long-term environmental effects, charging issues, smart adaptive structures.

MSFC Advanced Concepts

L'Garde 20-m System Ground Demonstrator

National Aeronautics and Space Administration

Sail Membrane

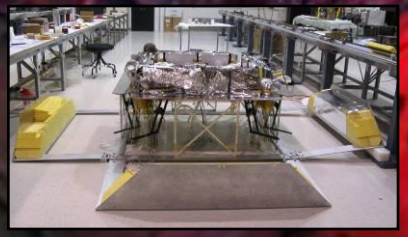
Inflatable Beams

Tip Vane

Tip Mandrel

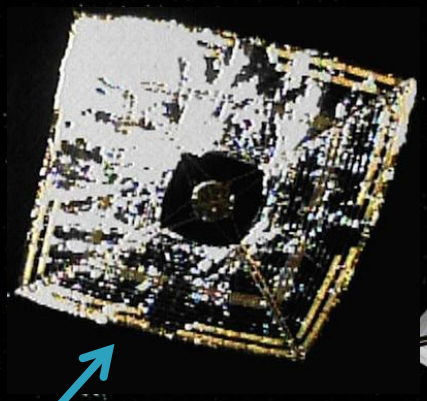
Vane Mechanism

20-M SGD



Stowed Configuration

Solar Sail Propulsion
Space Demonstrated



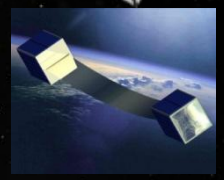
14-m IKAROS
Flying in space
(2010 JAXA)

~34-m space demo
OCT TDM 2014

Inflatesail
Lightsail

3.5-m NanoSail-D
Flown in Space (2010 NASA)

20-m ground demo (2005)



CubeSail